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JangJian et al.

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(54) **GRIDS IN BACKSIDE ILLUMINATION IMAGE SENSOR CHIPS AND METHODS FOR FORMING THE SAME**

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H01L 31/0232 (2014.01)
H01L 27/146 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 27/14632*** (2013.01); ***H01L 27/1464*** (2013.01); ***H01L 27/14687*** (2013.01); ***H01L 27/14689*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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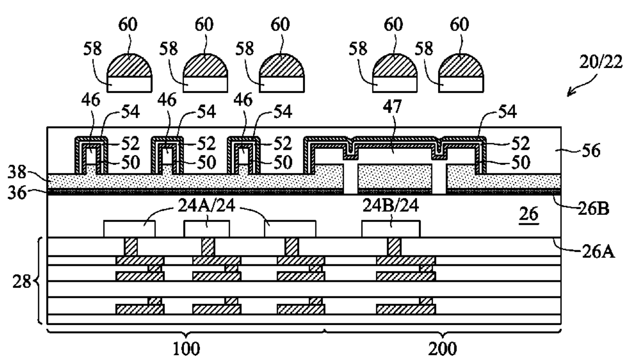
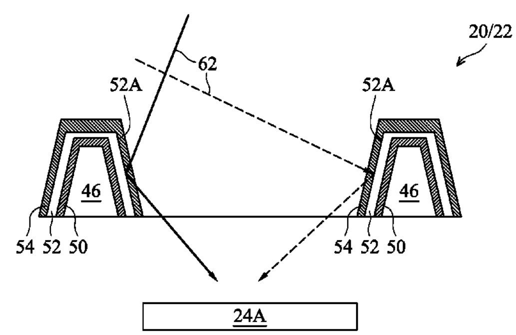
(57) **ABSTRACT**

A device includes a semiconductor substrate, which has a front side and a backside. A photo-sensitive device is disposed on the front side of the semiconductor substrate. A first and a second grid line are parallel to each other, and are disposed on the backside of, and overlying, the semiconductor substrate. A stacked layer includes an adhesion layer, a metal layer over the adhesion layer, and a high-refractive index layer over the metal layer. The adhesion layer, the metal layer, and the high-refractive index layer are substantially conformal, and extend on top surfaces and sidewalls of the first and the second grid lines.

20 Claims, 7 Drawing Sheets





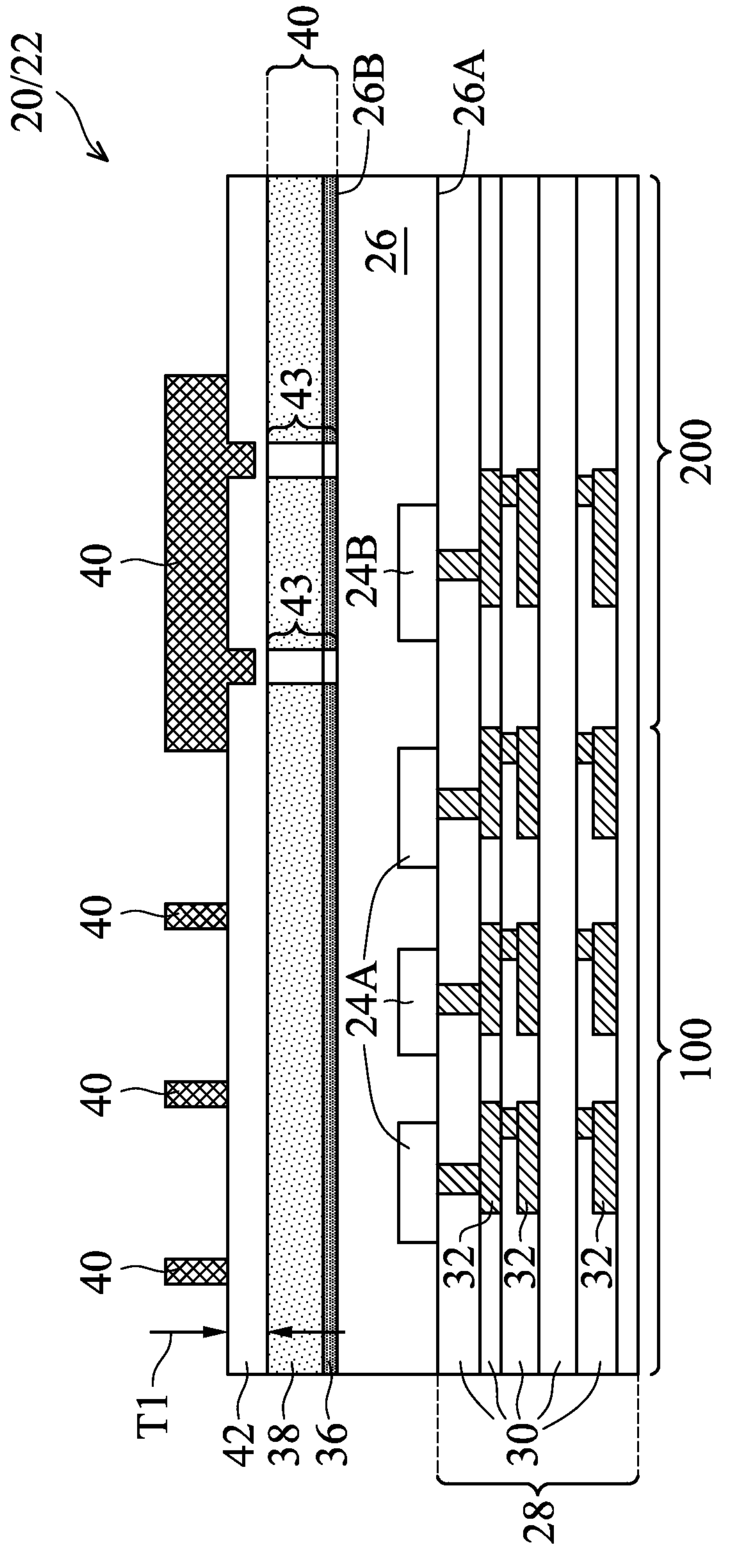


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FIG. 1

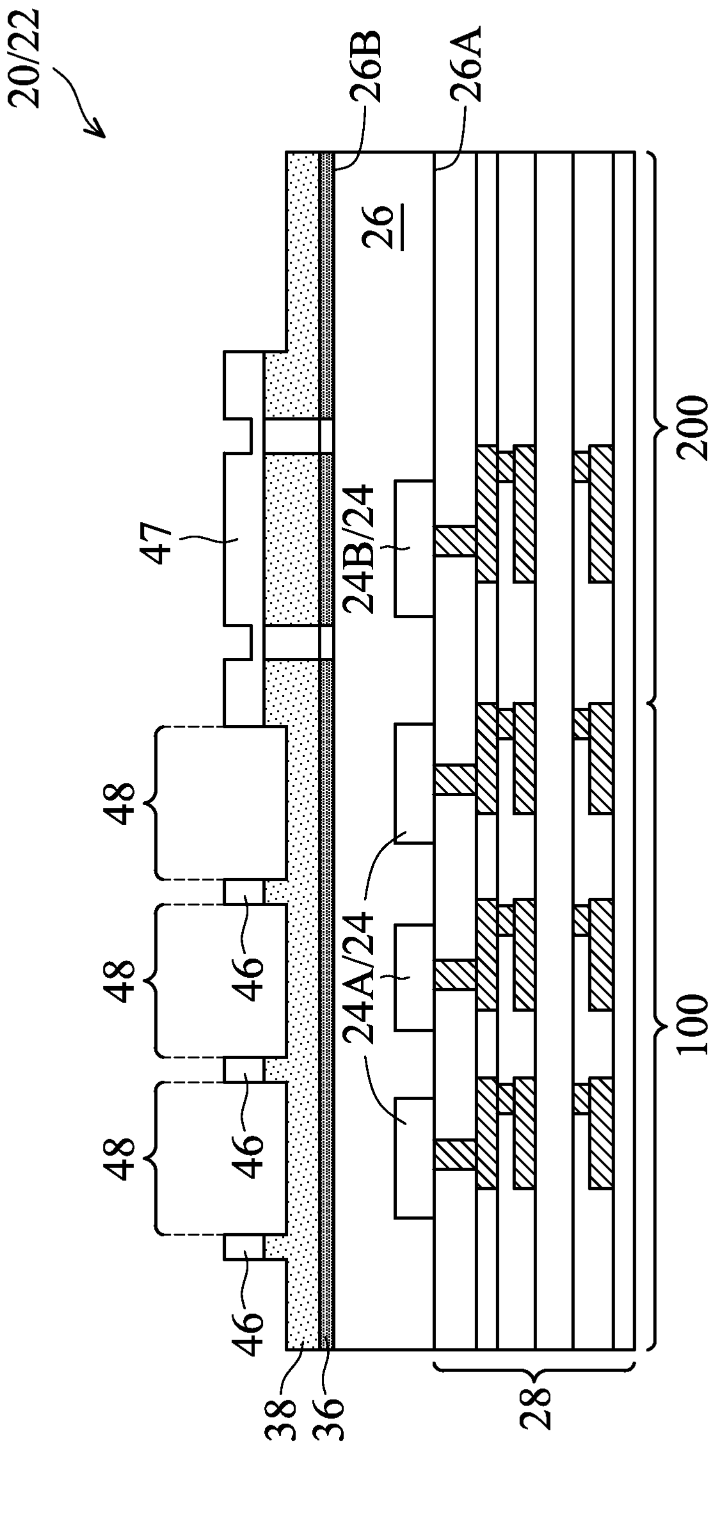

FIG. 2

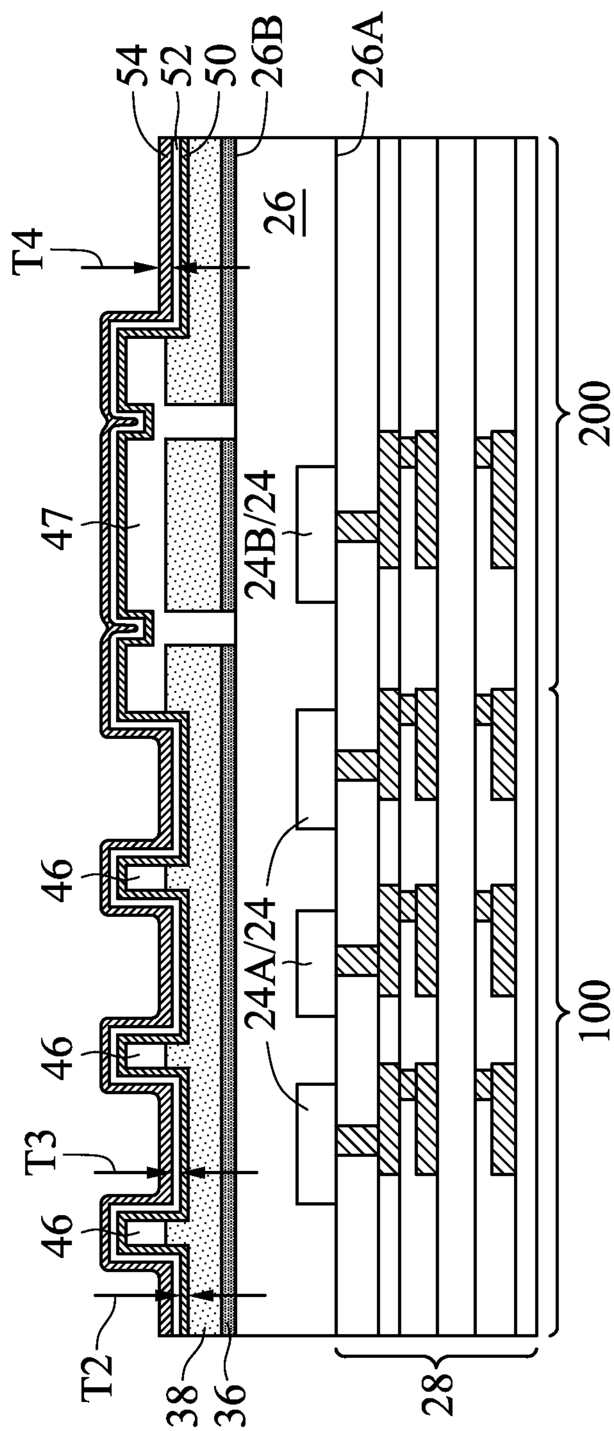
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FIG. 3

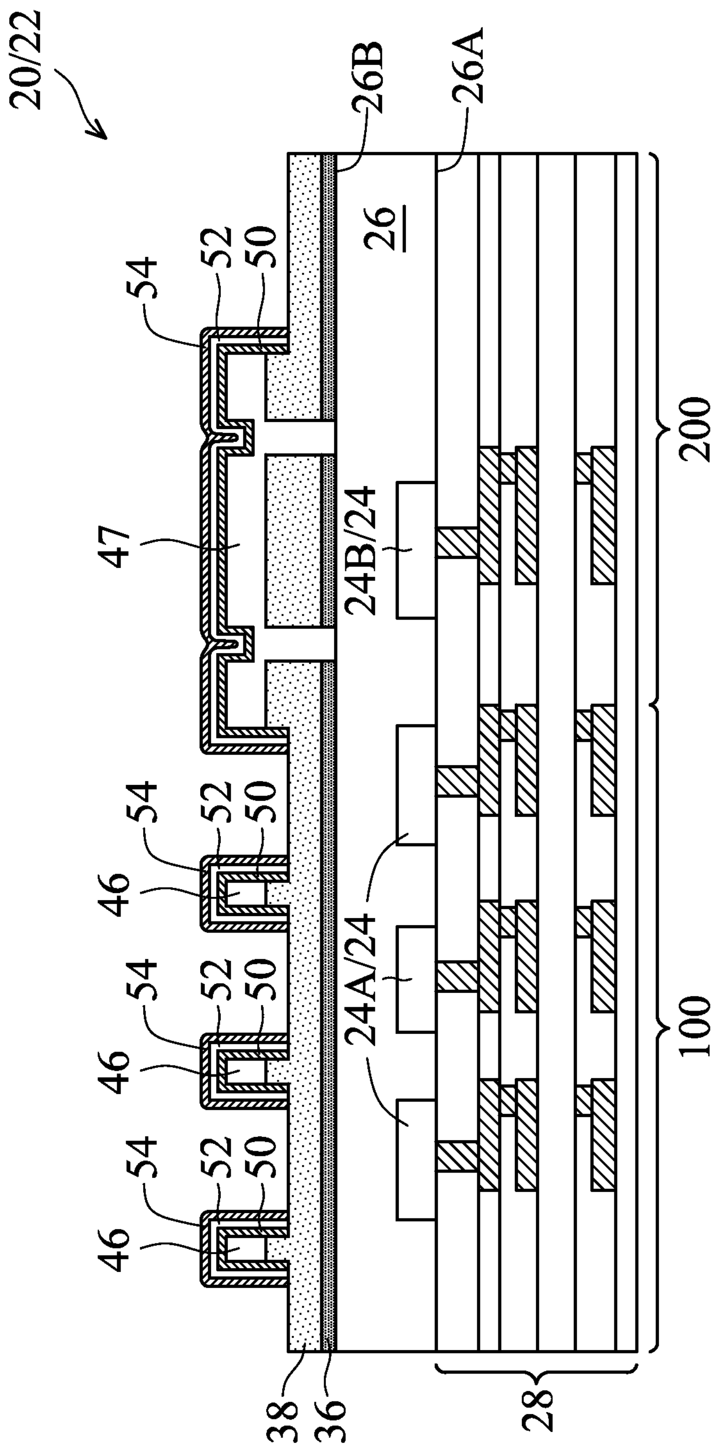
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FIG. 4

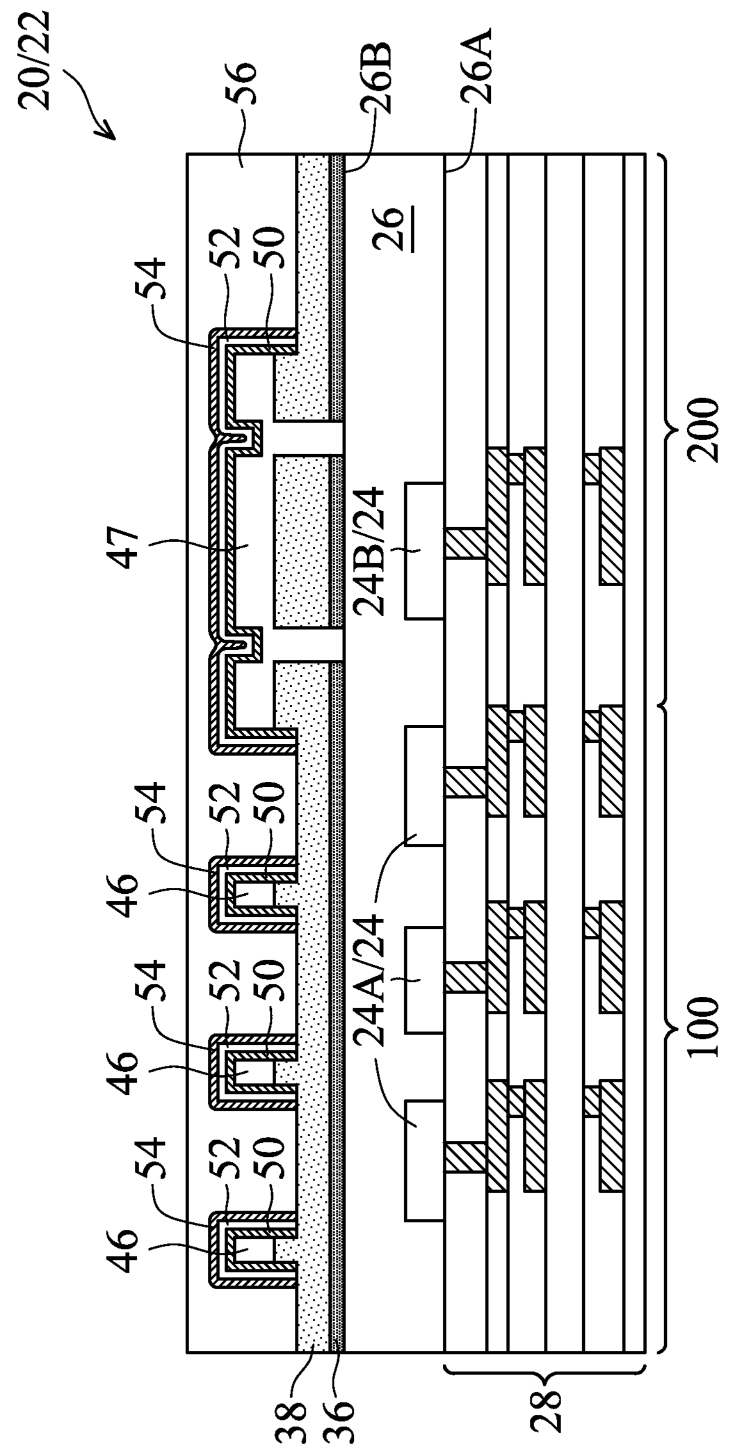
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FIG. 5

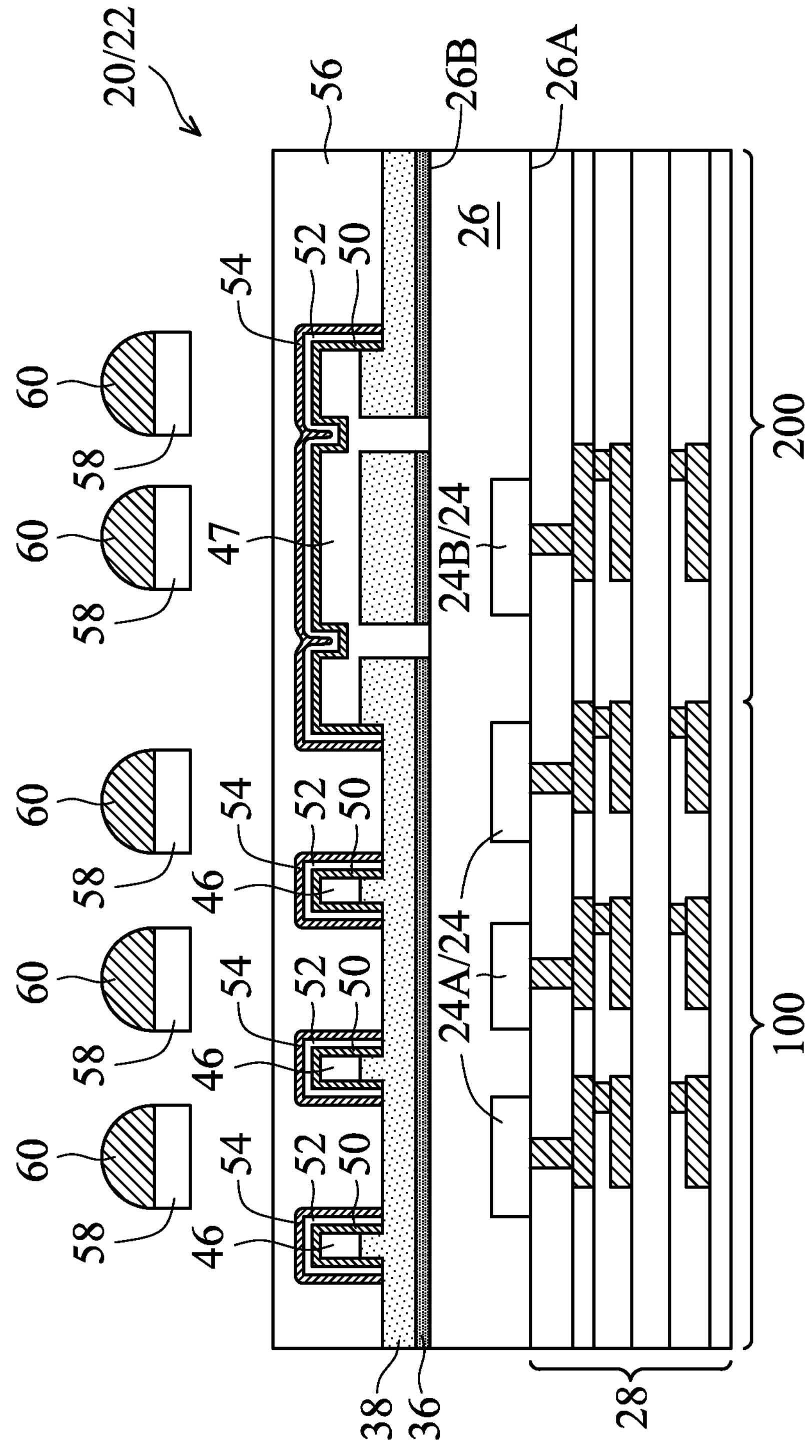
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FIG. 6

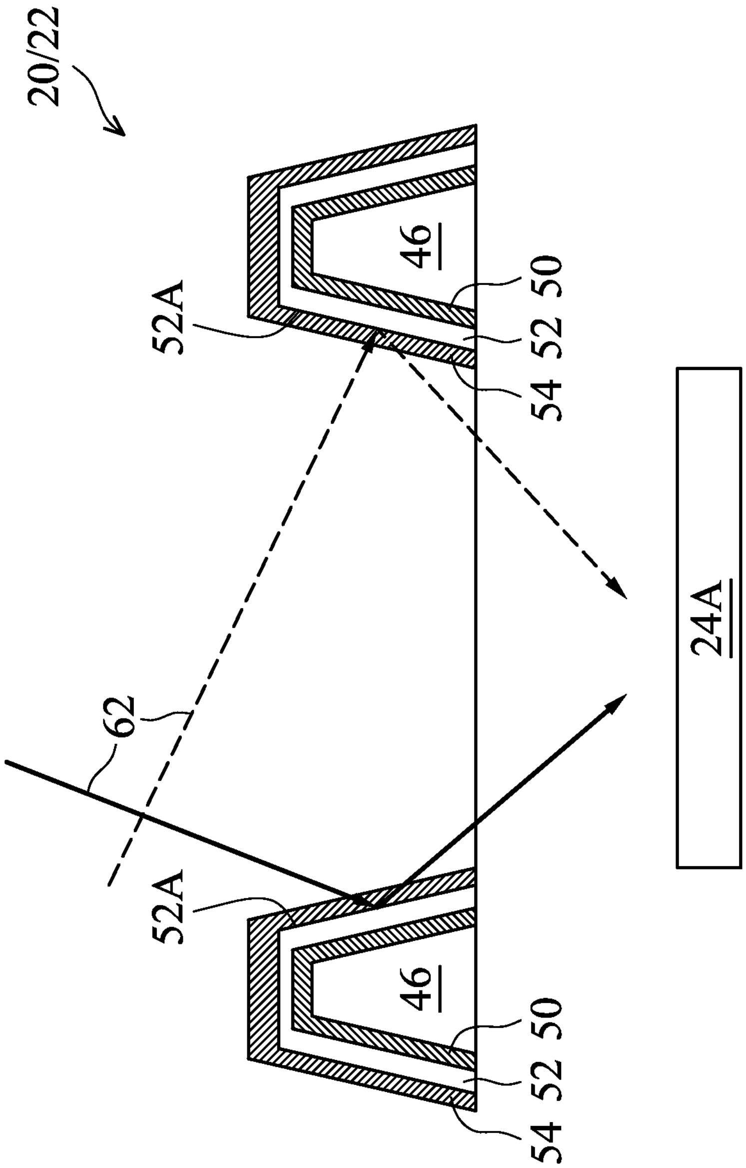

FIG. 7

GRIDS IN BACKSIDE ILLUMINATION IMAGE SENSOR CHIPS AND METHODS FOR FORMING THE SAME

BACKGROUND

Backside Illumination (BSI) image sensor chips are replacing front-side illumination sensor chips for their higher efficiency in capturing photons. In the formation of the BSI image sensor chips, image sensors, such as photo diodes, and logic circuits are formed on a silicon substrate of a wafer, followed by the formation of an interconnect structure on a front side of the silicon chip.

The image sensors in the BSI image sensor chips generate electrical signals in response to the stimulation of photons. The magnitudes of the electrical signals (such as the currents) depend on the intensity of the incident light received by the respective image sensors. To reduce the optical cross-talks of the light received by different image sensors, metal grids are formed to isolate the light. To maximize the quantum efficiency of image sensors, it is desirable that the light loss and optical cross-talk are minimized.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the embodiments, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGS. **1** through **6** are cross-sectional views of intermediate stages in the manufacturing of a grid structure in a Backside Illumination (BSI) image sensor chip in accordance with some exemplary embodiments; and

FIG. **7** schematically illustrates the light paths on the grid structure.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of the embodiments of the disclosure are discussed in detail below. It should be appreciated, however, that the embodiments provide many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are illustrative, and do not limit the scope of the disclosure.

A grid structure in a Backside Illumination (BSI) image sensor chip and the methods of forming the same are provided in accordance with various exemplary embodiments. The intermediate stages of forming the grid structure are illustrated. The variations of the embodiments are discussed. Throughout the various views and illustrative embodiments, like reference numbers are used to designate like elements.

FIGS. **1** through **6** illustrate the cross-sectional views of intermediate stages in the manufacturing of a grid structure in accordance with some exemplary embodiments. FIG. **1** illustrates image sensor chip **20**, which may be a part of an unsawed wafer **22**. Image sensor chip **20** includes semiconductor substrate **26**. Semiconductor substrate **26** may be a crystalline silicon substrate or a semiconductor substrate formed of other semiconductor materials. Throughout the description, surface **26**A is referred to a front surface of semiconductor substrate **26**, and surface **26**B is referred to as a back surface of semiconductor substrate **26**. Image sensors **24** (including **24**A and **24**B) are formed at surface **26**A of semiconductor substrate **26**. Image sensors **24** are configured to convert light signals (photons) to electrical signals, and may be photo-sensitive Metal-Oxide-Semiconductor (MOS) transistors or photo-sensitive diodes. Accordingly, the respective wafer **22** may be an image sensor wafer. In some exemplary embodiments, image sensors **24** extend from front surface **26**A into semiconductor substrate **26**. The structures of image sensors **24**A and **24**B may be identical to each other.

Front-side interconnect structure **28** is formed over semiconductor substrate **26**, and is used to electrically interconnect the devices in image sensor chip **20**. Front-side interconnect structure **28** includes dielectric layers **30**, and metal lines **32** and vias **34** in dielectric layers **30**. Throughout the description, the metal lines **32** in a same dielectric layer **30** are collectively referred to as being a metal layer. Front-side interconnect structure **28** may include a plurality of metal layers. In some exemplary embodiments, dielectric layers **30** include low-k dielectric layers and passivation layers. The low-k dielectric layers have low k values, for example, lower than about 3.0. The passivation layers may be formed of non-low-k dielectric materials having k values greater than 3.9. In some embodiments, the passivation layers include a silicon oxide layer and a silicon nitride layer on the silicon oxide layer.

Image sensor chip **20** includes active image sensor pixel region **100** and black reference pixel region **200**. Active image sensor pixel region **100** includes active image sensors **24**A formed therein, which are used for generating electrical signals from the sensed light. Image sensors **24**A may form an active image sensor pixel array including a plurality of image sensors arranged as rows and columns. Black reference pixel region **200** includes black reference image sensor **24**B formed therein, which is used for generating reference black level signals. Although one image sensor **24**B is illustrated, there may be a plurality of image sensors **24**B.

A backside grinding is performed to thin semiconductor substrate **26**, and the thickness of wafer **22** is reduced to smaller than about 30 μm, or smaller than about 5 μm, for example. With semiconductor substrate **26** having a small thickness, light can penetrate from back surface **26**B into semiconductor substrate **26**, and reach image sensors **24**A.

After the step of thinning, buffer layers **40** are formed on the surface of semiconductor substrate **26**. In some exemplary embodiments, buffer layers **40** include Bottom Anti-Reflective Coating (BARC) **36**, and silicon oxide layer **38** over BARC layer **36**. It is appreciated that buffer layers **40** may have different structures, and may have different number of layers other than illustrated.

Grid layer **42** is formed over buffer layers **40**. In some embodiments, grid layer **42** comprises a metal(s) or a metal alloy, wherein the metals in grid layer **42** include tungsten, aluminum, copper, and the like. In alternative embodiments, grid layer **42** may be a ceramic layer. Grid layer **42** may also be formed of partially transparent material, and may be a conductive layer or a dielectric layer. Thickness T**1** of grid layer **42** may be greater than about 500 Å, for example. It is appreciated that the dimensions recited throughout the description are merely examples, and may be changed to different values. Photo resist **44** is formed over grid layer **42**, and is then patterned.

The patterned photo resist **44** is used as an etching mask to etch through grid layer **42**. Referring to FIG. **2**, the remaining portions of grid layer **42** form grid lines **46**, which have lengthwise directions parallel to surface **26**A of substrate **26**. Grid lines **46** include a first plurality of grid lines parallel to each other, and a second plurality of grid lines parallel to each other. The first plurality of grid lines is perpendicular to the second plurality of grid lines **46** to form the grids. Grid openings **48** are formed between grid lines **46**. Each of grid openings **48** may be over and aligned to one of active image sensors 24A. The patterned grid layer 42 further includes portion 47 over and aligned to black reference image sensor 24B. Portion 47 is referred to as optical shield 47 hereinafter, which may be a metal shield or a ceramic shield.

FIGS. 3 and 4 illustrate the formation of a coating on grid lines 46, wherein the coating includes stacked layers. Referring to FIG. 3, adhesion layer 50, metal reflective layer 52, and high-refractive index layer 54 are formed. Each of layers 50, 52, and 54 may be a substantially conformal layer, with the vertical portions have substantially the same thicknesses as the horizontal portions of the respective layers. In some embodiments, adhesion layer 50 is a chromium layer, although other materials that can improve the adhesion between metal reflective layer 52 and grid lines 46 can be used. Thickness T2 of adhesion layer 50 may be between about 50 Å and about 200 Å in some exemplary embodiments. Metal reflective layer 52 may be a silver layer, which may be formed of substantially pure silver, for example, with the silver percentage greater than about 95 percent, or greater than about 99 percent. In alternative embodiments, metal reflective layer 52 may be an aluminum layer, which may be formed of substantially pure aluminum, for example, with the aluminum percentage greater than about 95 percent, or greater than about 99 percent. Thickness T3 of metal reflective layer 52 may be smaller than about 1,000 Å, and may be smaller than about 500 Å in some exemplary embodiments. It is noted that although metal layers with thicknesses lower than about 1,000 Å may be partially transparent, with the structures in accordance with embodiments, there is a near-perfect reflection of light on the surface of metal reflective layer 52, and hence the small thickness T3 does not adversely cause the optical cross-talk between different grids.

High-refractive index layer 54 may have a refractive index (n value) greater than about 1.5, or greater than about 2.0. In some embodiments, high-refractive index layer 54 is formed of silicon-rich oxide, which has a refractive index greater than about 1.5. The adjustment of the refractive index into the desirable range may be achieved by increasing the silicon percentage in high-refractive index layer 54. In alternative embodiments, high-refractive index layer 54 comprises a high-k dielectric material, which has a refractive index greater than 2.0. The exemplary high-k dielectric materials include hafnium oxide, lanthanum oxide, tantalum oxide, and combinations thereof. Thickness T4 of high-refractive index layer 54 may be between about 100 Å and about 1,000 Å, for example.

Referring to FIG. 4, adhesion layer 50, metal reflective layer 52, and high-refractive index layer 54 are patterned. The remaining portions of layers 50, 52, and 54 include first portions on the top surfaces and sidewalls of grid lines 46, and a second portion in black reference pixel region 200. The second portion may further include a top portion over optical shield 47, and sidewall portions on the sidewalls of optical shield 47. The horizontal portions of layers 50, 52, and 54 that are aligned to active image sensors 24A are removed.

FIG. 5 illustrates the formation of oxide layer 56, which may be a silicon oxide layer formed using Plasma Enhanced Chemical Vapor Deposition (PECVD). In some embodiments, a planarization step such as a Chemical Mechanical Polish (CMP) is performed to level the top surface of oxide layer 56. Oxide layer 56 fills grid openings 48, and may further include portions over grid lines 46. In subsequent process steps, as shown in FIG. 6, additional components such as color filters 58 and micro-lenses 60 are formed, with each of color filters 58 and micro-lenses 60 aligned to one of active image sensors 24A. In some embodiments, oxide layer 56 has a refractive index smaller than the refractive index of high-refractive index layer 54. The difference between the refractive index of high-refractive index layer 54 and oxide layer 56 may be greater than about 0.5, for example. The refractive index of oxide layer 56 may also be lower than 1.5.

FIG. 7 illustrates an amplified view of grid lines 46 and the overlying layers 50, 52, and 54. Arrows 62 represent exemplary light directions. Surfaces 52A of metal reflective layer 52 reflect light 62. In some embodiments, the reflectivity is greater than 95 percent, and may be greater than 98 percent. Accordingly, there is a great amount of light reflected and received by the respective active image sensors 24A. The quantum efficiency is thus improved. Furthermore, with more light being reflected on the surfaces of metal reflective layer 52, less light may penetrate through grid lines 46 to reach neighboring grids. The optical cross-talk is thus reduced, and the signal-to-noise ratio is increased.

Referring back to FIG. 6, layers 50, 52, and 54 are also formed in black reference pixel region 200. Accordingly, layers 50, 52, and 54 and the underlying optical shield 47 has improved ability for preventing light to penetrate through.

In accordance with embodiments, a device includes a semiconductor substrate, which has a front side and a backside. A photo-sensitive device is disposed on the front side of the semiconductor substrate. A first and a second grid line are parallel to each other, and are disposed on the backside of, and overlying, the semiconductor substrate. A stacked layer includes an adhesion layer, a metal layer over the adhesion layer, and a high-refractive index layer over the metal layer. The adhesion layer, the metal layer, and the high-refractive index layer are substantially conformal, and extend on top surfaces and sidewalls of the first and the second grid lines.

In accordance with other embodiments, a device includes a semiconductor substrate having a front side and a backside. A plurality of grid lines is disposed on the backside of the semiconductor substrate and forming a plurality of grids. A plurality of photo-sensitive devices is underlying and aligned to grid openings between the plurality of grid lines. The plurality of photo-sensitive devices is at the front side of the semiconductor substrate, and is configured to receive light from the backside of the semiconductor substrate, and convert the light to an electrical signal. A chromium layer includes top surface portions on top surfaces of the plurality of grid lines, and sidewall portions on sidewalls of the plurality of grid lines. A silver layer includes top surface portions and sidewall portions on the top surface portions and the sidewall portions, respectively, of the chromium layer. A high-refractive index layer includes top surface portions and sidewall portions on the top surface portions and the sidewall portions, respectively, of the silver layer.

In accordance with yet other embodiments, a method includes forming a plurality of photo-sensitive devices on a front side of a semiconductor substrate, forming a grid layer on a backside of the semiconductor substrate, and patterning the grid layer to form a plurality of grid lines. Grid openings between the plurality of grid lines are aligned to the plurality of photo-sensitive devices. A stacked layer is formed on top surfaces and sidewalls of the plurality of grid lines, wherein the step of forming the stacked layer includes forming an adhesion layer, forming a metal layer over the adhesion layer, and forming a high-refractive index layer over the metal layer. The stacked layer is patterned to remove the portions of the stacked layer that are aligned to the plurality of photo-sensitive devices.

Although the embodiments and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the embodiments as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, and composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the disclosure. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps. In addition, each claim constitutes a separate embodiment, and the combination of various claims and embodiments are within the scope of the disclosure.

What is claimed is:

1. A device comprising:

a semiconductor substrate having a front side and a backside;

a first photo-sensitive device disposed on the front side of the semiconductor substrate;

a first and a second grid line parallel to each other, wherein the first and the second grid lines are on the backside of, and overlying, the semiconductor substrate;

an adhesion layer;

a metal layer over the adhesion layer; and

a high-refractive index layer over the metal layer, wherein the adhesion layer, the metal layer, and the high-refractive index layer are substantially conformal, and extend on top surfaces and sidewalls of the first and the second grid lines.

2. The device of claim **1**, wherein the first photo-sensitive device is underlying and aligned to a space between the first and the second grid lines, and wherein the adhesion layer, the metal layer, and the high-refractive index layer are free from portions over and aligned to the first photo-sensitive device.

3. The device of claim **1**, wherein the adhesion layer comprises chromium.

4. The device of claim **1**, wherein the metal layer comprises silver.

5. The device of claim **1**, wherein the first and the second grid lines comprise a ceramic.

6. The device of claim **1**, wherein the high-refractive index layer comprises silicon oxide, and has a refractive index greater than 1.5.

7. The device of claim **1**, wherein the high-refractive index layer comprises a high-k dielectric material, and has a refractive index greater than about 2.0.

8. The device of claim **1** further comprising:

a second image sensor disposed on the front side of the semiconductor substrate; and

an optical shielding layer over and aligned to the second image sensor, wherein the optical shielding layer is formed of a same material as, and is at substantially a same level as, the first and the second grid lines, and wherein the adhesion layer, the metal layer, and the high-refractive index layer extend on a top surface of the optical shielding layer.

9. A device comprising:

a semiconductor substrate having a front side and a backside;

a plurality of grid lines on the backside of the semiconductor substrate and forming a plurality of grids;

a plurality of photo-sensitive devices underlying and aligned to grid openings between the plurality of grid lines, wherein the plurality of photo-sensitive devices is at the front side of the semiconductor substrate, and is configured to receive light from the backside of the semiconductor substrate and convert the light to an electrical signal;

a chromium layer comprising top surface portions on top surfaces of the plurality of grid lines, and sidewall portions on sidewalls of the plurality of grid lines;

a silver layer comprising top surface portions and sidewall portions on the top surface portions and the sidewall portions, respectively, of the chromium layer; and

a high-refractive index layer comprising top surface portions and sidewall portions on the top surface portions and the sidewall portions, respectively, of the silver layer.

10. The device of claim **9**, wherein the chromium layer, the silver layer, and the high-refractive index layer are substantially conformal layers.

11. The device of claim **9**, wherein the chromium layer, the silver layer, and the high-refractive index layer do not comprise portions aligned to the plurality of photo-sensitive devices.

12. The device of claim **9**, wherein the plurality of grid lines is metal lines.

13. The device of claim **9**, wherein the plurality of grid lines is ceramic lines.

14. The device of claim **9** further comprising:

an image sensor disposed on the front side of the semiconductor substrate; and

an optical shielding layer over and aligned to the image sensor, wherein the optical shielding layer is formed of a same material as, and is at substantially a same level as, the plurality of grid lines, and wherein the chromium layer, the silver layer, and the high-refractive index layer extend on a top surface and sidewalls of the optical shielding layer.

15. A device comprising:

a semiconductor substrate;

a photo-sensitive device on a first side of the semiconductor substrate;

a first grid line and a second grid line parallel to each other;

a third grid line and a fourth grid line parallel to each other and perpendicular to the first grid line and the second grid line, wherein a space defined by the first grid line, the second grid line, the third grid line, and the fourth grid line is aligned with the photo-sensitive device, and the first grid line, the second grid line, the third grid line, and the fourth grid line are on a second side of the semiconductor substrate opposite to the first side;

an adhesion layer extending on a top surface and sidewalls of each of the first grid line, the second grid line, the third grid line, and the fourth grid line;

a metal layer over the adhesion layer, wherein the metal layer comprises a top portion over a top surface portion of the adhesion layer, and sidewall portions on sidewalls of the adhesion layer;

a high-refractive index layer over the metal layer; and

an oxide layer filling a space between the first grid line and the second line, wherein the space is further between the third grid line and the fourth grid line.

16. The device of claim **15**, wherein the adhesion layer is a substantially conformal layer.

17. The device of claim **15**, wherein the oxide layer comprises a portion level with the adhesion layer.

18. The device of claim **15**, wherein the high-refractive index layer comprises silicon oxide, and has a refractive index greater than about 1.5.

19. The device of claim **15**, wherein the high-refractive index layer comprises a high-k dielectric material, and has a refractive index greater than about 2.0.

20. The device of claim **15**, wherein the adhesion layer comprises chromium, and the metal layer comprises silver.

* * * * *